Khulna University
Life Science School
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Author(s): Mouri Islam

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Supervisor(s): Md. Obaidullah Hannan, Professor, Forestry and Wood Technology Discipline, Khulna University

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MANUFACTURE OF BAMBOO-CEMENT COMPOSITES FROM

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COURSE TITLE: THESIS WORK

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Supervisor

Md. Obaidullah Hannan
Professor
Forestry and Wood Technology Discipline
Khulna University
Khulna-9208
Bangladesh

Submitted By

Mouri Islam

Mouri Islam
Roll No. 090512
Forestry and Wood Technology Discipline
Khulna University
Khulna-9208
Bangladesh

Dedicated To My Beloved parents

DECLARATION

I, Mouri Islam, declare that this thesis is based on my own original works based on previous literature under the continuous supervision of Professor Md. Obaidullah Hannan, Forestry and Wood Technology Discipline, Khulna University, Khulna and it has not been submitted or accepted for a degree in any other university.

I, hereby, give consent for my thesis, if accepted, to be available for any kind of photocopying and for inter-library loans.

Signature:

Mouri Islam

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Mouri Islam

ABSTRACT

Manufacture of cement-bamboo composites from *Melocanna baccifera)* were studied. The average density of cement bonded particle board was 942.806 kg/m^3. . In this observation it has found that where higher proportion of cement shows highest density and the reverse shows lower density. The moisture content of cement bonded particle board was ranges from (9-18) % and water absorption of cement bonded particle board ranges from (4.091-29.003 %). The moisture content and water absorption of the various board specifications were higher where there was reduced proportion of cement inclusion. Again thickness swelling in this study ranges 8.40% to 15.368% and linear expansion 3.169% to 8.486%. In this case the thickness swelling and linear expansion of the various board specifications were higher where there was reduced proportion of cement inclusion. The average Modulus of Rupture (MOR) of cement bonded wood ranges from 1.2 Nmm^2 to 4.80 Nmm^2 and Modulus of Elasticity (MOE) of cement bonded wood ranges from 437.132 Nmm^2 to 1889.45 Nmm^2. The bamboo chips and cement 1:4 ratio shows the highest modulus of rupture (MOR) and Modulus of Elasticity (MOE). The bamboo chips and cement 1:2 ratio shows the lowest modulus of rupture (MOR) and Modulus of Elasticity (MOE).

TABLE OF CONTENTS

LIST OF FIGURES

ABBREVIATIONS

AD	Air dry dimension
Anon	Anonymous
APCC	Asia and Pacific Coconut Community
APFSOS	Asia and Pacific Forestry Sector Outlook Study
ASTM	American Society for Testing and Materials
BFRI	Bangladesh Forest Research Institute
cm^3	Cubic Centimeter
EMC	Equilibrium Moisture Content
FAO	Food and Agricultural Organization
ft.	Feet
g	Gram
GD	Green dimension
ha	Hectare
Kg	Kilogram
m^3	Cubic meter
mm	millimeter
OD	Oven dry dimension
RBD	Randomized Block Design
SD	Standard Deviation
N	Newton

CHAPTER ONE
INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1 JUSTIFICATION AND BACKGROUND OF THE STUDY

Bangladesh is a country of south-east Asia. It is well known as a developing country. There are many problems in this country, which are said to be major obstacles in the development of this country. Excessive Population is said to be the worst among all current problems. Forestry plays a significant role in Bangladesh, contributing to the livelihood and subsistence needs of this predominantly rural population. It provides a source of energy, supplies forest products such as fuel-wood, fodder, timber, poles, thatching grass, medicinal herbs, construction materials and contributes to the conservation and improvement of the country's environment. There will be challenges in expanding the ability of forest to meet the needs the societies worldwide. To meet the demand of expanding pressure, alternative raw materials are major concern of the world. All natural material is considered as environment friendly and cement is one of them. Environmental concern about the disposal of waste materials has focused renewed attention on low density cement bonded wood composites (CBWCs).

There are different types of cement bonded board and these are cement bonded particle board (CPB), cement bonded fiberboard and wood wool cement bonded board.

Today, wood-cement panels have found acceptance in a number of countries as a result of certain desirable characteristics. The development and use of wood-cement panels attest to their attraction as building materials. In addition to their resistance to fire, these materials have a special attraction for use in warm, humid climates where decay and termites are a major concern (Jorge *et al.*, 2004). The cement binder provides a durable surface as well as one that can be easily embossed and closed for an alternate, low finished product. The raw materials uses are compatible with a range of processing methods to provide a variety of products that are easily machined with conventional wood working tools.

Cement bonded wood composites (CBWCs) take advantage of wood in its high specific stiffness, fracture toughness, strength to weight ratio, renewable natural resource, low cost as well as flexibility during processing, thermal and acoustic resistance, while the cement component acts purely as binder with a barrier layer to retard moisture intrusion and resistant against biological attack. More importantly, they are much better suited to fire, bio-deterioration and weathering applications to which solid wood and resin bonded composites are vulnerable (Dinwoodie and Paxton, 1991).

Cement-bonded wood composite boards are extremely versatile and have a wide application than any other wood composite board product. Cement-bonded wood particle board is a composite somewhat similar to cement-asbestos board. In the past, these panels have consisted of excelsior and magnesite and have been primarily used a slow-density insulating materials. In the early 1960s, a high density cement-bonded structural flake board was developed leading to expanded applications (Deppe 1974).

More importantly however, Cement bonded particle board (CBP) performs like concrete and wood. It has been proven to withstand adverse effects of tropical cyclones, seasonal monsoon rains and high humidity. Cement bonded particle board (CBP) has the required strength as well as the resistance to high humidity in the tropical climate. These composites are strong, stiff and resistance to moisture, fire, fungi and insects. In panel form, they are being utilized for structural and non structural application in both interior and exterior situations. Discovering the new methods of manufacturing technologies to replace the conventional ones and expanding its raw materials are some of the aspects that are increasing in momentum (Moslemi, 1989).

Bangladesh is a densely populated country. To meet the demand of this increasing population we have to think alternative way of using forest resources. For this reason we are using cement bonded board from muli bamboo (*Melocanna baccifera).*

1.2 OBJECTIVES OF THE STUDY

- To develop the manufacturing technique of the cement-bonded board from muli bamboo *(Melocanna baccifera).*
- To evaluate the physical and mechanical properties of cement bonded board from muli bamboo *(Melocanna baccifera).*

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Muli Bamboo (*Melocanna baccifera*)

2.1.1 Vernacular Names

Assam - Tarai; Bengal - Muli, Cachar - Wati; Garo - Watrai; Manipur - Moubi; Mikir - Arten; Nagaland - Turiah; Sylhet - Bajail; Dhaka - Nali.

2.1.2 Description

Muli bamboo is evergreen bamboo, clump diffuse. Culms 10-20 m high, 3-7 cm diameter, green when young, straw colored when old; longest internodes 20-25 cm long. Culm-sheaths 10-15 cm long, yellowish green when young and yellowish brown on maturity, brittle, striate, truncate or concave at the tip, glabrous or sparsely with whitish apprised hairs on the back. Ligules very short with undulated or toothed margin, auricles small, sub-equal, membranous, fringed with silvery bristles, blade deciduous, usually 15-30 cm long, 2-3 cm broad, subulate. Young shoots are smooth, light purple or purplish green; ligules with long hairs, soon caducous, blades linear, green. Leaves 15-30 cm long, 2.5-5 cm broad, oblong lanceolate, apex acuminate, leaf sheath thick, ligulate; auricles very small with silvery bristles. Inflorescence a large compound panicle of one-sided drooping, spicate branches, bearing clusters of 3 to 4 spikelets in the axils of short, blunt, glabrous bracts, empty glumes 2-4. Palea glabrous, convolute, mucronate, acuminate not keeled. Lodicules 2, narrow, linear-oblong, obtuse and erose-fimbriate at the tip. Stamens free at base or irregularly joined, filaments flat; anthers yellow notched at the apex; ovary ovoid; style elongâte, divided into 2-4 hairy recurved stigmas. Caryopsis very large, fleshy, pear-shaped, the stalk is inserted at the thick end and the apex terminates in a curved beak.

The species can be recognized easily by diffused clump habit, having Culm-sheath straight for about two-third of the way up, then once or twice transversely waved with subulate flagelliform blade (Alam, 1982).

2.1.3 Flowering and Fruiting

Flowering has been reported during 1863, 1866, 1892, 1893, 1900-1902, 1910-1912, 1933 and 1960 (Chatterjee, 1960; Vaid, 1972). Sporadic flowering was reported in Cachar and Manipur in 1967 (Nath, 1968). Sharma (1992) reported flowering at FRI, Dehra Dun. Flowering and fruiting was observed at Pune during 1993. Length of flowering period according to Gamble (1896) is 30 years, according to Kurz (1876) is 30-35 years, according to Troup (1921) is about 45 years. Culms and rhizomes die after flowering. Profuse natural regeneration has been observed.

Seed is green, smooth, sessile, very large having a mid length and diameter of 6.9- 7.2 cm and 4.1-4.3 cm, respectively; obliquely ovoid, thick fleshy, onion shaped and the apex terminating in a curved beak. There is no endosperm in the ripe seed, but it has a 7-13 mm thick white to creamy colored fleshy pericarp filled with starch just below the green surface of the seed. A more or less round shaped white-colored embryo with a broad fleshy cotyledonary body is present inside the seed cavity. The fruit is not a true caryopsis, it can be termed as a bacciform caryopsis. Vivipary is observed.

2.1.4 Distribution and Ecology

The species is distributed in India, Bangladesh and Myanmar, cultivated in many Asian countries. In India, it is mainly seen in Assam, Manipur, Meghalaya, Mizoram, Tripura, West Bengal and other parts of Eastern India in the plains and low hills (Biswas *et al.*, 1991). Also found in Singtam, East Sikkim. It is seen in cultivation in Maharashtra and parts of Karnataka. It grows almost equally on the well-watered sandy clay loam, alluvial soil and on the well drained residual soils consisting of almost pure sand even at the summits of the low sand stone hills. It springs up in practically pure patches where natural forests have been cleared for agricultural purposes (McClure, 1966).

2.1.5 Anatomy and Fiber Characteristics

The epidermis is made up of long cells alternating with short cells longitudinally. The long epidermal cells uniform in width (about 7.4 µm) with undulating walls, vary in length from 16.5 µm-122 µm. The cell wall is thick and septa-like partitions absent. One pair of short cells alternate with an epidermal cell, two pairs of short cells present occasionally. The cork cells small and rectangular or reniform. Silica cells very small, angular or rectangular. The average number of short cell couples is 1894 per mm2. Bicellular and fan-like hairs common often occurring in place of short cells. Spines present, few, mostly solitary, as many as 22 per microscopic field (0.17 mm2). The average number of stomata is 10 per field (Ghosh and Negi, 1960). In Culm macerates three fiber types are seen; very thick, thick, and thin walled. Septate fibers absent, fiber tips pointed, blunt or forked and wall lamellation 4-7-layered. Slenderness ratio 142.2, flexibility ratio 75.6, Runkel ratio 0.8, fibre length 2.68 mm; fibre diameter 14.37 µm, lumen diameter 4.08 µm, wall thickness 5.15 µm, parenchyma 20 per cent (Singh *et al.*, 1976).

2.1.6 Chemistry

Proximate chemical analysis showed ash 1.9 per cent, cold water soluble 3.25 per cent, hot water soluble 6.4 per cent, alcohol benzene soluble 1.43 per cent, ether soluble 0.81 per cent, caustic soda soluble 18.97 per cent, pentosans 15.13 per cent, lignin 24.13 per cent, cellulose 62.25 per cent (Bhargava, 1945). Analysis of hemicellulose showed 17.3 per cent yield with the following sugars, pentosans 79.8 per cent, methoxyl 0.8 per cent xylose 79.4 per cent, arabinose 79.4 per cent, rhamnose 0.2 per cent, glucose 16.2 per cent, glucuronic acid 2.1 per cent (Rita Dhawan and Singh, 1982).

Beating characteristics of the species showed caustic soda 25 per cent; kappa no.25; lignin in bamboo 27 per cent, in pulp 4.1 per cent, pentosans in bamboo 19.6 per cent, in pulp 15.5 per springs up in practically pure patches where natural forests have been cleared for agricultural purposes (McClure, 1966).

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2.1.7 Silviculture and Management

One clump produces about 5-7 Kilogram of seeds. Average seed weight is about 55.3 g. In a sample of 1000 seeds, the length, diameter and weight varied from 3.6- 10.9 cm, 0.2-6.1 cm and 7.8-150.6 g, respectively. Freshly collected seeds have high viability (78.4%). Under normal conditions the viability is for about 35 days. Storage under air dry condition prolongs viability to 45 days and storage in dry sand in jute bags up to 60 days (Banik, 1991). Seeds have a high germination percentage under shade (negatively photoblastic). Mature seeds germinate even in storage. Number of shoots produced from a single seed vary from 1-6.

Fresh seeds start germination within 5-7 days and continue for the next 20-25 days. Shoots are thick (4-6 mm) soft and conical in shape. Germination is hypogeal. Survival and health of seedlings are influenced by seed weight. Seeds can be classified into three grades according to weight. Seedlings from the medium and light seeds develop abnormalities like stunted radicle, albino forms, leafless plumule and radicals growing upward. Generally 1 to 2 plumules develop and form 1-2 stems. Soon after 2-3 weeks of germination fibrous roots develop from the base of young shoot. Shoots emerge successively, new shoots are taller, bigger and biomass gradually increases, recording 86.7g in about 10 months. Rhizome development starts within 40 days after germination. The leaves produced by seedlings are bigger than the mature leaves (Banik, 1991).

Seedlings are kept in the nursery for 10-12 months before planting in the next rainy season. To prevent inter logging between seedlings; they are transplanted to other beds after six months. Pruning of the three months old seedling stem tip induce bud activation. The excised seedlings become woody and it minimizes seedling damage during transportation (Banik, 1991).

This species is easy to regenerate from rhizomes. Rhizomes with one to two buds may be planted at a spacing of 4 to 5 m. Using culms cuttings rooting up to 75 per cent is obtained from two-year-old culms. Such propagules produce on an average 20 culms after 4 years of transplanting (Saharia and Sen, 1990). Treatment with growth regulating substances enhances rooting response. The offsets can be planted during April to June. Younger offsets of about one year-old showed better survival than the older ones. It is better to plant 2-3 offsets at a time than a single offset.

Due to elongated rhizome necks, the culms are produced at varying intervals in all directions forming a diffuse and open type of clump formation, which can accommodate the space required for the increased number of Culm production in later years. Due to this type of growth, the pattern of clump expansion is different in this species.

2.1.8 Pests and Diseases

Root rot caused by Poria rhizomorpha, has been reported from North Bengal and Assam. Emerging culm mortality (about 10%) is reported (Banik, 1983).

2.1.9 Physical and Mechanical Properties

Strength properties tested under air dry condition showed moisture content of 12.8 per cent, specific gravity 0.751, fiber stress at elastic limit 43.4 N/mm2, modulus of rupture 57.6 N/mm2, modulus of elasticity12.93 kN/mm2 and compression strength parallel to grain 69.9 N/mm2.

2.1.10 Uses

This species is used for building houses, for making woven ware and as an important source of superior paper pulp. It is highly suitable for Kraft paper making. The culms are strong, durable with inconspicuous nodes. 'Tabasheer' an ancient elixir of Manipur can be isolated from the culms and branches. Fruits are edible. The culms are used for making floats to transport wooden logs. Enormous logs can be transported by these floats.

Bamboo can be used as an alternative source of raw materials for wood-based industries because it can grow in various soils, is fast growing, can grow in short rotation, and has desirable properties. Bamboo has long been recognized as a multi-purpose plant. Bamboos in Indonesia are planted on the edges of home gardens called pekarangan and intermixed with other wood-producing and food producing plants. Bamboo is also used to mark village boundaries and to control erosion along riverbanks. There are 35 bamboo species growing in Indonesia belonging to 13 genera, but only 13 species are economically valuable. Some of these species have been cultivated for hundreds of years. People, especially those who live in villages, use bamboo in their daily lives for construction materials (village houses), furniture, household utensils and handicrafts. However, the shape and the hollow form of the bamboo Culm limit the use of bamboo as a building material. Furthermore, bamboo is readily attacked by insects. One alternative that overcomes the low natural durability of bamboo is to use it for the manufacture of cement-bonded boards.

Cement-bonded board

2.2 Cement-bonded board

Cement-bonded board is a promising product that uses wood-wastes as its main raw material. Manufacture does not require sophisticated equipment and hence the board can be made in small, rural based plants using simple technology. It can also be manufactured in industrial areas using the by-products of forest industries. Manufactured boards find a ready market for housing and construction, but they need to meet certain standards governing their physical and mechanical properties. Furthermore, since there are many deteriorating agents in Indonesia, boards need to possess resistance to decay and attack by termites.

Bamboo–cement boards were significantly more resistant to termite attack than the solid parent wood species.

Cement-bonded board, as its name suggests, is a composite product that uses cement as binder. It has better durability than other composite products glued with organic binders, since the cement improves the resistance of the board to fungi, heat and fire. Furthermore, researchers have found that wood–cement composites also have well dimensional stability, insulation, nailing, and machining properties. Bamboo–cement boards can also be produced in a wide range of dimensions. However, the setting time of cement is often prolonged by substances in the bamboo, especially simple sugars. These inhibiting substances can sometimes be removed by soaking the bamboo in cold or hot water

2.2.1 Factors Affecting the Properties of Cement Bonded board

Mechanical and physical properties, dong with other important properties like fire resistance, sound absorption, and Motion behavior, are primarily influences by the density of the products and the binder / wood ratio as well as the ratio of water to cement, proper ratios not only influence panel properties adversely, they can also make processing difficult- The binders are applied as a powder or as a slurry. Water is required as a homogenizer during the mixing process, as a solvent during the hardening reactions, and also as a component in the chemical hydration process. The optimum water cement ratio is approximately 0.4. Currently, Commercial cement bonded particleboard; incorporating 2.75 to 3.0 parts of Portland cement to 1.0 part of wood particles (weight basis) are reported to attain acceptable mechanical and physical properties.

The quantity of water added to the wood-cement mixture was calculated using a relationship developed by Simatupang (1979). In his formulation, the water requirement was determined as follows:

$$\text{Water (liters)} = 0.35C + (0.30 - MC)\,W$$

Where C = cement weight (kg)

MC = wood MC (oven-dry basis) W = oven-dry wood weight (Kg)

Moslemi et al (1987) examined the influence of decreasing cement-wood or cement-bamboo ratio from m 3.0 to 1.5 at 0.5 increments on flexural and dimensional stability properties of cement –bonded composite panels.

2.2.2 Types of cement-bonded board

There are four main types of wood-cement board which are Wood Wool Cement Board (WWCB), Cement-bonded particle board (CBP), Cement-bonded fiber board and Cement-bonded oriented standard board. Each type of the composites gives different type of characteristic and properties. Moreover, the technology involved in the manufacture of each of these types of composites is different.

2.2.3 Wood Wool Cement Board (WWCB)

Wood Wool Cement Board is a versatile, ecologically pure and safe construction material, meeting all criteria of comfortable and safe housing. WWCB is made of wood-wool and Portland cement with addition of natural mineralizing agent.

Wood wool is band-like fibers 0. 2 – 0.5mm thick, 3 - 5 mm wide and up to 25 mm long, cut on the special equipment. It has a function of filler in content of fiberboard. Due to this feature, wood-wool slabs have valuable properties of timber, as a natural, ecologically pure material, its strength and perfect thermal insulation.(Portland cement is water resistant and frost proof)(The content of cement provides ready slabs with durability and long-term service life)

High content of wood in WWCB makes them similar by ecological properties to wood mass, at the same time; the cement provides WWCB with durability and long service life allows using them as a perfect construction material.

The production of WWCB had already spread over Europe in the thirties, several years after wood wool gypsum boards and wood wool magnetite boards were successfully produced and applied in Austria. After 1950 WWCB has spread world-wide. In industrialized countries automatic plants were installed, in developing countries usually only certain essential sections to reduce the investment and to employ people. Until recently no fully automatic WWCB plant could be supplied, since all wood wool shredding machines were manually operated. Besides being unhealthy and dangerous for the operators these machines produce wood wool of an inconsistent quality, while the capacity is relatively low.

The worldwide acceptance of Wood Wool Cement Board proves its versatility and, not least important, its durability in any climatic condition. The main characteristics are:

- Fire resistance
- Wet and dry rot resistance
- Termite and vermin resistance
- Thermal insulation
- Acoustic performance – sound absorption
- Acceptance of a wide range of finishes

WWCB has a unique combination of structural, thermal, fire resistant and acoustic properties making it a highly versatile construction material. It is extremely lightweight, termite and fungus resistant, easy to use and an environmentally friendly alternative to the conventional building systems use today.

2.2.4 Manufacturing process of Wood Wool cement bonded

Raw Materials

a) Cement: Normal Portland cement as a hydraulic binder.

b) Wood-wool: (excelsior)

c) Chemical solution:

a) Calcium chloride ($CaCl_2$) mostly used,

or b) Magnesium chloride ($MgCl_2$)

or c) Silicate of soda (Na_2Sio_3)

Production process

The two processes described here are the fully automatic wood-wool cement slab production plant and the semi-automatic plant which follows the Van Elten method.

(i) Fully-automatic plant

By means of conveyor belts or tubes, the wood-wool produced by the planing machines is supplied to the wood-wool weighing machine without any intermediate storage (this eliminates the danger of fire). In the weighing machines, the wood-wool is weighed to attain accurate cement dosing. If more wood-wool comes from the planning machine caused by thicker wood logs, then automatically more cement will be dosed.

From the wood-wool weighed, the wood-wool goes on to the submersion unit. The moistened wood-wool, after adjustable remoistening, is then passed to a continuous mixer. At the same time an accurately measured quantity of cement is automatically added to the mixer from the cement dosing silo by a dosing screw. The cement dosing silo is automatically filled from the main silo. The quantities of wood-wool and cement supplied to the mixer are thoroughly mixed there and continually supplied to the filling machine.

At the same time, empty moulds (from plywood sheets with fixed longitudinal wooden ridges) are supplied by the automatic stripping machine via the mould-supplier and the mould-cleaning and oiling machines to the filling machine. In the filling machine the mixture is further stirred up and distributed into the continuously moving moulds, after being dosed the required weight by means of a dosing belt weighed.

The moulds containing the mixture pass through the side pressing equipment, the roll press, the steadier and the separating saw which runs along with the moulds and which automatically separates the individual moulds accurately between mould ends.

The individual moulds with material are then brought to the piling press, where they are automatically piled up under pressure to piles of e.g. 25, whilst at the same time, by means of hydraulic operated steel plates; the usual forming of whiskers is prevented.

Without any interruption of the production rhythm, the piling press automatically pushes the pile of slabs on the roller conveyor behind the piling press, where the pile *is* taken away by the fork lift truck. This truck arranges the slabs for preliminary sorting. A special pallet having recesses at the top is put on this pile beforehand by the fork lift truck operated to enable him to put a second pile on the first one. The double pile of new board remains under pressure for 25 hours. The pressure is produced by concrete weights. One pallet and concrete weight are required for every 50 moulds. Then the hardened slabs are taken out of the moulds, they are conveyed to the edge-stressing saw where the longitudinal edges of the slabs are cut and cleaned of raised fibers. Then, the slabs are automatically moved in a transverse direction and cut off to a length of 2 meters at their cross sides. At the same time the firm's mark is printed on.

(ii) Semi-automatic plant

The semi-automatic plant basically follows the same sequence of procedures as the automatic plant with the exception that some processes are done manually such as mould stripping and slab piling.

2.2.5 Cement-bonded particle board (CBP)

Cement bonded particleboard is a construction board, the surface of which is smooth and cement grey colored. Its main components are cement and fine wood chip fractions.

Cement-bonded particleboard is made-up of Portland cement and wood fibers. It is retailed in sheets of varying thicknesses. Different kinds of softwoods like beech, pine and spruce for making particleboards. A particleboard is cut with a disc-chipper. After cutting the wood into particles, it is allowed to dry. Resin is applied to glue the particles together and render the board, more stability. These glued particles are then shaped into sheets. Cement-bonded particleboard is available with square edges or a tongue-and-groove combination. It is often finished with a factory-applied sealer for additional protection against moisture. Cement-bonded particleboard is available as graded density particleboard or the conventional, three-layer particleboard.

Cement-bonded particleboard, previously known as wood-cement particleboard, is available in the United Kingdom under a number of brand names. It has evolved as a high-density, smooth-surfaced board suitable for both interior and exterior use. This paper describes the physical and mechanical properties of the board and summarizes existing guidance on how it can be used successfully.

Machining of cement bonded particleboards requires the use of carbide tipped saw blades with the maximum tooth pitch of 6 mm. For boring carbide tipped borers shall be used. The boards shall be installed on a wooden frame by ensuring deformation joints between the boards or boards shall be placed overlapping. In deformation joints joint tape or joint and corner stripes of matching color may be used. In case of large areas in external conditions a drip steel plate should be used in horizontal joints.

For fixing the boards it is required to use screws made of stainless steels and pre-bored holes with the size of 0.8 – 1.1 x fastening screw diameter. When fastening the screws too tight fixing and screwing in the board should be avoided – the board shall have slight space to move. Countersunk-head screws shall not be used for fixing the boards. To ensure the screw head is level with the surface of the board a wider chamfer may be pre-bored in the surface.

Cement-bonded particleboard is used for making bookcases, cabinet-ends and countertops, making it a useful interior-remodeling choice. The surface of particleboard is often laminated to make it look like hardwood.

The boards are-

- Strong, wear and impact resistant
- Resistance to temperature and moisture fluctuation caused by weather conditions
- Flame resistant
- Frost resistant
- Environmentally friendly
- Do not contain substances hazardous to health
- Insect and fungal resistant
- With good sound insulation properties
- Easy to install
- Durable

2.2.6 Manufacturing process of cement bonded particle board

Raw Materials

Wood particle, Rice husk, Straw, Bamboo, Cement, Water

Wood chips

Comprising by weight about 70-75% Portland cement and 20-30 % wood chips, similar to those used in the manufacture of chip board, the board is heavy with a density of about 1200 Kg/m^3. A different mineralising chemical of 2% by weight of cement (calcium chloride, magnesium chloride, aluminium sulphate and an admixture of sodium silicate and aluminium sulphate) is mixed with the mixture. The CBP are mat formed on caul plates. After this it is kept under pressure for 24 h in a hardening chamber maintained at a temperature range of 60 to 65^0 C. The pressure on the CBP was released after 24 h and the CBP were allowed to cure for 28 days at room temperature.

2.2.7 Cement-bonded fiber board

Cement-bonded fiber board is produced from fiber which we can get from either wood or non woody materials. Wood-fiber reinforced cement-bonded boards are manufactured from wood-fiber (7-8.5%), sand (60%), cement (30%), and aluminium trihydrate (3-4%). The wood-fiber is usually obtained from softwood chemical pulp. They act as a reinforcing agent in the boards, a role previously played by asbestos fibers in an older generation of building materials. The manufacture involves washing the sand and reducing it to a fine powder using a ball mill. Fibers are then refined or beaten twice in conical refiners to make the ability to interact with sand and cement higher. The proportions outlined above are combining the cement, sand, fibers and addictives and diluted to form slurry with a solids content of 10%.

2.2.8 Manufacturing process of cement bonded fiber board

Raw Materials

Wood fiber, Coconut coir fiber, Additives ($CaCl_2$), Cement , Water

Wood fiber

After separating fiber from wood, distilled water – $CaCl_2$ solution is first sprayed on predetermined amount of air-dried wood fibers, and thoroughly blended. Cement is subsequently added and the constituents are mixed until the cement paste is completely hydrated. The quantity of distilled water will be added, can be calculated using the following formula (Fuwape, 1995).

$$\text{Water (liters)} = 0.35\,C + (0.30 - MC)\,W$$

Where:

C = cement weight (Kg)

MC (%) = wood fibers moisture content (oven-dry basis)

W = oven-dry wood fiber weight (Kg).

After 10 min of mixing, the paste mixture was screened onto a metal plate which had been covered with wax paper. The mat is evenly distributed to provide as uniform a density as possible. Cold pressing took place under a pressure of 5 MPa to a 9 mm thickness, after which the board is retained in compression for 24 h. After manufacturing, the boards are conditioned at 20°C and 65 % relative humidity.

2.2.9 Cement-bonded oriented standard board

In this type of board, the particles are narrower with a width about half their length, and more importantly, these standards are aligned either in each of three layers or only in the outer two layers of board. In latter case, the surface and core layers are oriented approximately at right angles to each other in order to produce a board which stimulates the structure of plywood. The extent of orientation varies among manufactures and the ratio of property levels in the machine to cross direction can vary from 1.25:1.00 to 2.50:1.00, these figures similar to that of plywood, but very much lower than the degree of anisotropy in timber. This board is used as a floor decking, roof decking, in packaging and in temporary shuttering (Desch and Dinwoodie, 1996).

2.2.10 Manufacturing process of Cement-bonded oriented standard board

The standard size of wood particle is 75 mm × 20 mm × 0.75 mm (length× width × thickness). The particles are air dried to approximately 10 % moisture content (MC). The bonding agent is Portland cement type 1. Ammonium chloride (NH_4Cl_2-2 % based on weight of cement) is introduced into cement slurry to accelerate cement set during hydration. A predetermined amount of air-dried particles and an ammonium chloride (anhydrous) distilled water solution are thoroughly blended. After 15 minutes of manual mixing, the cement-wood water is screened onto a caul. The mat is evenly distributed to provide as uniform a density as possible and pre-pressed to a thickness of approximately 50 mm. cold pressing take place under an initial pressure of 2- 5 MPa, depending on the cement to wood ratio to a 16 mm thickness, after which the board is retained compression for 24 hours. To minimize cement capillary desiccation and enhance hydration and enhance hydration, boards are misted with distilled water, then wrap in cellophane before storing for curing at 20°c and 65 % relative humidity for a month.

2.2.11 Importance of cement bonded board

- Cement bonded boards are strong, stiff and resistance to moisture, fungi and insects. Fire resistance is being higher than any other materials. In panel form, they are being utilized for structural and non structural application in both exterior and interior purposes.
- It reduces thermal conductivity and increase sound insulation.
- An added advantage over massive concrete panels is their ability to withstand larger deformation before failure.
- Present world is very much concern about environmental pollution. All the formaldehyde based resin binders are more or less toxic to the environment. But it is free from formaldehyde, isocynates, wood preservatives, lindane and fungicides.
- As cement bonded board can be manufactured from conventional process, it saves energy. Every year, greater portion of energy is needed for particle board industries. But cement bonded board can be made by natural process. So, it needs not electrical energy.
- It can be produced by either labor-incentive or machine incentive operations, whichever is most economically feasible. Owing to the binder used.
- It can be used as erection of free standing solid partition; various sound damming partition constructions.
- It is easy to cut to size to service fabrication prior to site.
- It is easy to fix.
- It is frost resistant.
- It is biologically safe.
- It can be decorated with different finishes which is helpful to diversify its uses.
- It is moisture proof and for this it can be used in damp conditions.
- It is paintable which is helpful to design with our own requirements.
- It can be disposed of on a landfill site.

CHAPTER THREE

MATERIALS AND METHOD

CHAPTER THREE

MATERIALS AND METHODS

3. Materials and Methods

3.1 Raw materials collection

Muli Bamboos (***Melocanna baccifera***) were collected from Gollamari in Khulna district, Bangladesh. Portland cement was collected from the market of Khulna.

3.2 Preparation of raw materials

Muli Bamboos were chipped and grinded by the grinder machine.

3.3 Mixing of cement with chips

Three types of board were prepared using three ratio of oven dry chip to cement i.e. 1:4, 1:3 and 1:2 where bamboo is used by same proportion. First attempt of 1:1 ratio was prepared but failed. Required amount of chips and cement were taken for making each type of board. Chips were mixed with cement at first. Then required amount of water was added to the mixture so that it can be distributed evenly.

3.4 Mat formation

The mat was formed using an iron frame and that iron frame was placed on a polythene sheet. After that, mixture was distributed in the frame equally in a layer

3.5 Curing

After mat formation, each type of board was kept for 28 days to cure. Water was given in the board for 28 days.

3.6 Trimming and sanding

Each type of board was trimmed after curing. After trimming, each type of board was sanded.

3.7 Flow diagrams of Cement bonded particleboard production

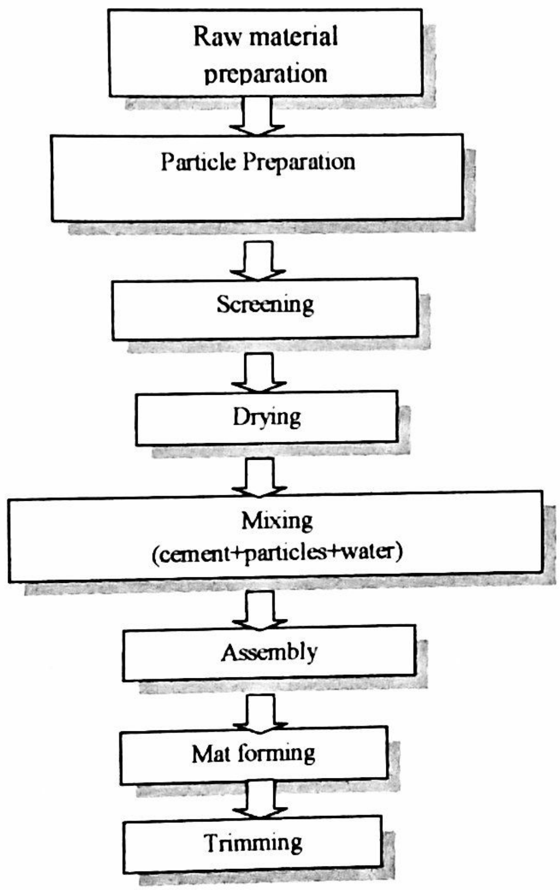

Fig. 3.1: Flow diagrams of cement bonded particleboard production

3.8 Laboratory Tests

The laboratory tests for characterization of physical properties and mechanical properties for each type of particleboards were carried out respectively in the Wood Technology Laboratory of Forestry and Wood Technology Discipline of Khulna University, Bangladesh and in the Laboratory of Civil Engineering Department of Khulna University of Engineering and Technology, Khulna, Bangladesh. All the tests were carried out according to the Malaysian Standard specifications for wood cement board, MS 934:1986. The testing specifications according to this standard are almost identical to the International specification for CBP, ISO 8335: 1987 (Anon, 1985). All the test data were analyzed by the statistical analytical system for ANOVA and Duncan's multiple ranges.

3.9 Preparation of samples for testing

Three replications of each type of boards were manufactured as stated earlier. For testing physical properties, three samples were collected from each board of each type. So the total number of sample was nine (9) for each type of particleboard for testing of physical properties. The Density and Moisture Content were determined on the same nine (9) samples and the Water Absorption, Thickness Swelling and Linear Expansion were determined on the other nine (9) samples. Some samples for testing physical properties were collected from the samples for testing mechanical properties after being mechanical properties testing completed.

For testing mechanical properties, three samples were collected from each board of each type. So the total number of sample was nine (9) for each type of particleboard for testing of mechanical properties. The MOR and MOE were determined on the separate samples.

The dimension of samples for testing the physical properties was approximately (5.5 cm x5.5 cm) and for testing the mechanical properties was approximately (32 cm x5 cm).

3.10 Board evaluation

3.10.1 Density

Density of each sample was with the following formula-

$$\rho = \frac{m}{v} \quad \text{(Desch and Dinwoodie, 1996)}$$

Where, ρ = Density in gm/cm^3;

m = Mass of the sample in gm

and v = Volume in cm^3.

3.10.2 Moisture content

The moisture content was determined, from the differences in weights before and after the sample has been drying in the oven. Initial and final weight of the samples was measured by electric balance. It was calculated by the following formula-

$$MC\ (\%) = \frac{m_{int} - m_{od}}{m_{od}} \times 100 \quad \text{(Desch and Dinwoodie, 1996)}$$

Where,

MC = Moisture content (%)

m_{int} = Initial mass of the sample (gm)

m_{0d} = Oven-dry mass of the sample (gm)

3.10.3 Water absorption

Water absorption is defined as the difference in weight before and after immersion in water and expressed in percentage. The water absorption was calculated by the following formula-

$$A_w = \frac{m_2 - m_1}{m_1} \times 100$$

Where,

A_w = Water absorption (%)

m_2 = The weight of the sample after (24 hr.) immersion in water (gm)

m_1 = The weight of the sample before immersion in water (gm)

3.10.4 Thickness swelling

Thickness swelling was calculated by the following formula-

$$G_t = \frac{t_2 - t_1}{t_1} \times 100$$

Where,

G_t = Thickness swelling (%)

t_2 = Thickness of sample after immersion (24 hr.) in water (mm)

t_1 = Thickness of sample before immersion in water (mm)

3.10.5 Linear expansion

The Linear Expansion was calculated by the following formula-

$$LX(\%) = \frac{L_A - L_B}{L_B} \times 100$$

Where,

L_A = Length of sample after immersion (24 hr.) in water (mm)

L_B = Length of sample before immersion in water (mm)

3.10.6 Modulus of rupture (MOR)

Modulus of rupture (MOR) was measured with the Universal Testing Machine (UTM), model: WE-100, made by Time Group Inc. in the Laboratory of Civil Engineering Department of Khulna University of Engineering & Technology, Khulna.

The MOR was calculated from the following equation-

$$MOR = \frac{3PL}{2bd^2}$$ (Desch and Dinwoodie, 1996)

Where,

MOR is the modulus of rupture in N/mm^2

P= Load in N

L= Span length in mm

b= width of test sample in mm

d= Thickness of test sample in mm

3.10.7 Modulus of elasticity (MOE)

The Modulus of elasticity (MOE) was also measured with the Universal Testing Machine (UTM) in the Laboratory of Civil Engineering Department of Khulna University of Engineering & Technology, Khulna. The modulus of elasticity (MOE) was calculated from the following equation-

$$MOE = \frac{P'L^3}{4\Delta bd^3}$$ (Desch and Dinwoodie, 1996)

Where,

MOE is the modulus of elasticity in N/mm^2

P' is the load in N at the limit of proportionality

L is the span length in mm

Δ is the deflection in mm at the limit of proportionality

b is the width of sample in mm

d is the thickness/depth of sample in mm

3.11 Analysis of Data

Completely randomized design was used in the experiment and all the data produced during the laboratory tests for characterization of physical and mechanical properties of each type of boards, were analyzed by using SAS-6.12(Statistical Analysis System) software. ANOVA (Analysis of Variance) and LSD (Least Significant Difference) were done to analyze the data.

CHAPTER FOUR
RESULTS AND DISCUSSION

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

The results of different physical and mechanical properties that were found during different laboratory tests are delineated (with standard error bar) here.

4.1.1 Physical Properties

4.1.1.1 Density

Three types of boards were manufactured as per volume by volume basis ratio of 1:4, 1:3, 1:2 of muli bamboo (*Melocanna baccifera*) chips and cement. The board density of 1:4 volume by volume ratio was 1225.23 kg/m^3, 1280 kg/m^3, 1223.1 kg/m^3. The board density of 1:3 volume by volume ratio was 993.051kgm/m^{3,} 955818 kg/m^3, 1007.48 kg/m^3 and the board density of 1:2 volume by volume ratio was 886.15 kg/m^3 , 733.091 kg/m^3, 740.98 kg/m^3.The figure (4.1) shows different type of density. The variation in density among the different types of cement bonded particleboards may be due to the variation of the different amount of raw materials.

Bamboo chips: cement, 1:4 volume by volume basis ratio shows highest value and bamboo chips: cement, 1:2 volume by volume basis ratio shows lowest value.

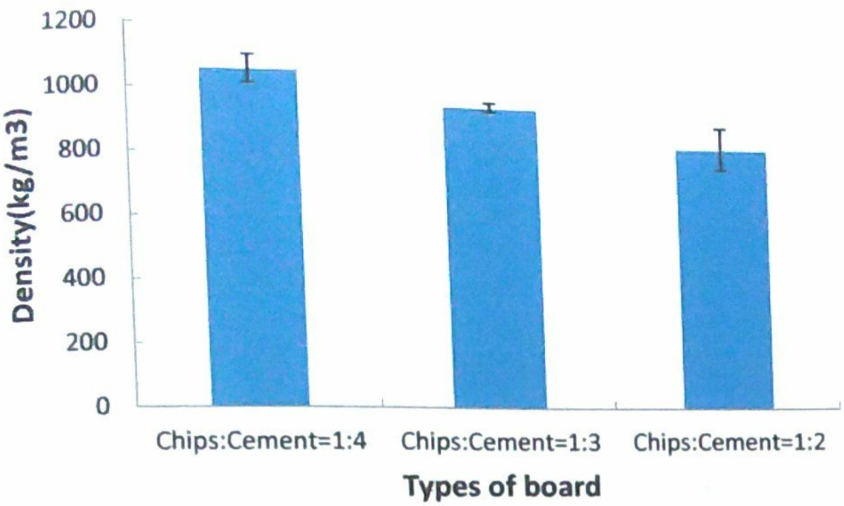

Fig.4.1: Density of cement-bamboo composites from Muli Bamboo (*Melocanna baccifera*) chips.

From the analysis variance (Appendix-1), it has been found that, there is significant difference for density among the ratio of bamboo chips and cement (DF=2, F=26.46 and P<0.0001).

4.1.1.2 Moisture content

The moisture content of 1:4 volume by volume basis ratio was 12.04%, 12.62%, 12.74% respectively. The moisture content 1:3 volume by volume basis ratio was 9.80%, 11.26%, 12.83% respectively and the moisture content of 1:2 volume by volume basis ratio was 19.96%, 20.87%, 23.75% respectively.Table-4.2 shows that the Muli bamboo (*Melocanna baccifera*) chips: cement 1:2 volume by volume basis ratio shows the highest moisture content and the Muli bamboo (*Melocanna baccifera*) chips: cement 1:4 volume by volume basis ratio shows the lowest moisture content

This difference of showing moisture content may due to the use of highest amount of cement and free from spongy particles.

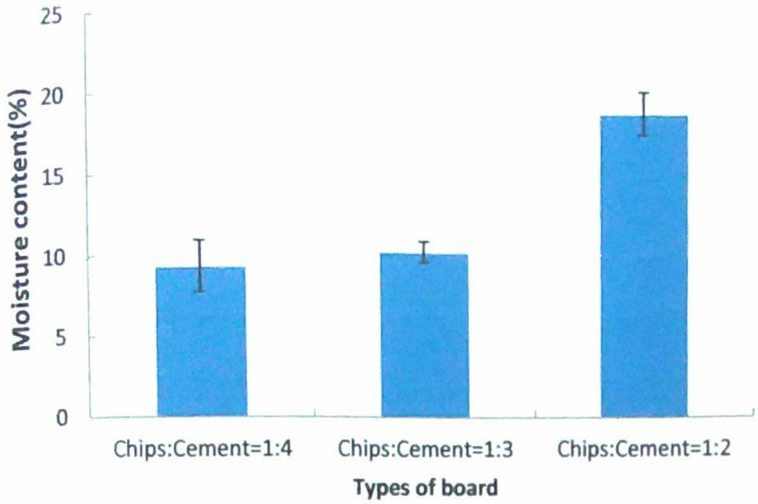

Fig.4.2: Moisture content of cement-bamboo composites from Muli Bamboo (*Melocanna baccifera*) chips.

From the analysis of variance (Appendix-2), it has been found that, there is significant difference for moisture content among the ratio of bamboo chips and cement(DF=2,F=17.45 and P<0.0001).

4.1.1.3 Water absorption

The water absorption of Muli bamboo chips and cement ratio 1:4, 1.3 and 1:2 was 4.89%, 5.23%, 5.35%, 16.39%, 16.59%, 18.78%, 32.97%, 30.79%, 34.56% respectively. Table-4.3 shows that the bamboo chips: cement 1:2 volume by volume basis ratio shows the highest water absorption and the bamboo chips: cement 1:4 volume by volume basis ratio shows the lowest water absorption.

The causes behind this may be the variation among the ratio of cement denotes lower water absorption due to lower void space.

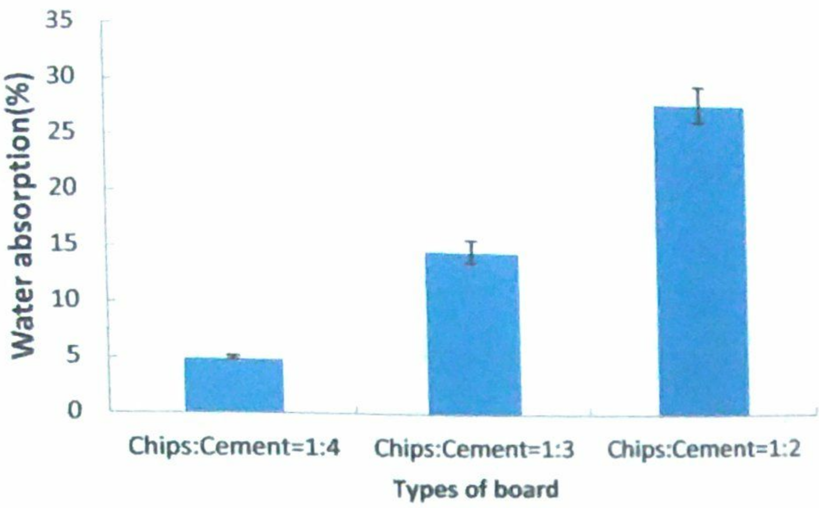

Fig.4.3: Water Absorption of cement-bamboo composites from Muli Bamboo (*Melocanna baccifera*) chips.

From the analysis of variance (Appendix-3), it has been found that, there is significant difference for moisture content among the ratio of bamboo chips and cement(DF=2,F=113.02 and P<0.0001).

4.1.1.4 Thickness swelling

The thickness swelling of Muli bamboo chips and cement volume by volume basis ratio 1:4, 1:3 and 1:2 was 10.3068%, 5.4909%, 9.42529%, 8%, 12.5%, 13.0435%, 12.2645%, 16.667%, 17.1739% respectively. Table-4.4 shows that the bamboo chips: cement 1:2 volume by volume basis ratio shows the highest thickness swelling and the bamboo chips: cement 1:4 volume by volume basis ratio shows the lowest thickness swelling.

The causes behind this may be the variation among the ratio of cement denotes lower thickness swelling due to lower void space.

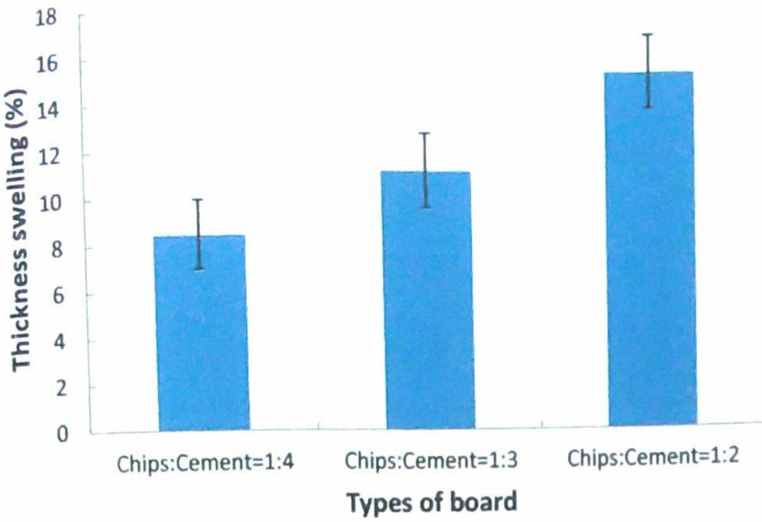

Fig.4.4: Thickness Swelling of cement-bamboo composites from Muli Bamboo (*Melocanna baccifera*) chips.

From the analysis of variance (Appendix-4), it has been found that, there is significant difference for thickness swelling among the ratio of bamboo chips and cement(DF=2,F=5.13 and P<0.0502).

4.1.1.5 Linear expansion

The linear expansion of Muli bamboo chips and cement volume by volume basis ratio 1:4, 1:3, 1:2 was 2.56%, 4.14%, 2.80%, 7.09%, 4.64%, 5.24%, 8.10%, 10.39%, 6.96% respectively. Table-4.5 shows that the bamboo chips: cement 1:2 volume by volume basis ratio shows the highest linear expansion and the bamboo chips: cement 1:4 volume by volume basis ratio shows the lowest linear expansion.

This may be due to the reason stated above as well the lower pressure.

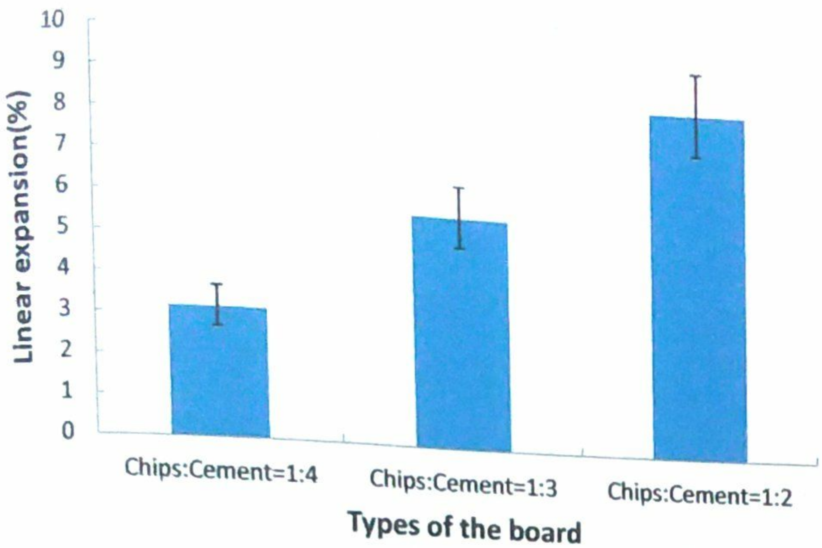

Fig.4.5: Linear Expansion of cement-bamboo composites from Muli Bamboo (*Melocanna baccifera*) chips.

From the analysis of variance (Appendix-5), it has been found that, there is significant difference for linear expansion among the ratio of bamboo chips and cement (DF=2, F=11.75 and P<0.0084).

4.1.2 Mechanical Properties

4.1.2.1 Static Bending Strength

4.1.2.1.1 Modulus of Rupture (MOR)

The Modulus of Rupture (MOR) of Muli bamboo chips and cement volume by volume basis ratio 1:4 was 3.70 N/mm^2, 5.02 N/mm^2 and 6.62 N/mm^2 respectively. The Modulus of Rupture (MOR) of Muli bamboo chips and cement volume by volume basis ratio 1:3 was 1.80 N/mm^2, 2.54 N/mm^2, 2.90 N/mm^2, and N/mm2 respectively. Again The Modulus of Rupture (MOR) of Muli bamboo chips and cement volume by volume basis ratio 1:2 was 0.62 N/mm^2, 1.57 N/mm^2 and 1.61 N/mm^2 respectively. Table-4.6 shows that the bamboo chips: cement 1:4 volume by volume basis ratio shows the highest Modulus of Rupture (MOR) and the bamboo chips: cement

1:2 volume by volume basis ratio shows the lowest Modulus of Rupture (MOR). The causes behind this may be the variation among the ratio of cement.

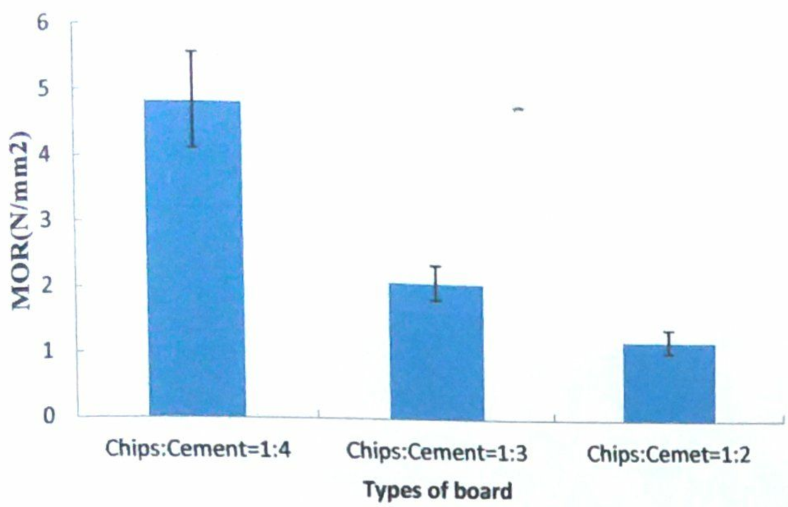

Fig.4.6: Modulus of Rupture of cement-bamboo composites from Muli Bamboo (*Melocanna baccifera*) chips.

From the analysis of variance (Appendix-6), it has been found that, there is no significant difference for modulus of rupture (MOR) among the ratio of bamboo chips and cement (DF=2, F=16.27 and P>0.0004).

4.1.2.1.2 Modulus of Elasticity (MOE)

The Modulus of Elasticity (MOE) of bamboo chips and cement volume by volume basis ratio 1:4 was 2029.96N/mm^2, 2581.69 N/mm^2 and 3050.49 N/mm^2. The Modulus of Elasticity (MOE) of bamboo chips and cement volume by volume basis ratio 1:3 was 641.08 N/mm^2, 773.13 N/mm^2 and 820.94 N/mm^2. The Modulus of Elasticity (MOE) of bamboo chips and cement volume by volume basis ratio 1:2 was 389.15 N/mm^2, 543.21 N/mm^2 and 615.94 N/mm^2 respectively. Table-4.7 shows that the bamboo chips: cement 1:4 volume by volume basis ratio shows the highest Modulus of Elasticity (MOE) and the bamboo chips: cement 1:2 volume by volume basis ratio shows the lowest Modulus of Elasticity (MOE).

The causes behind this may be the variation among the ratio of cement.

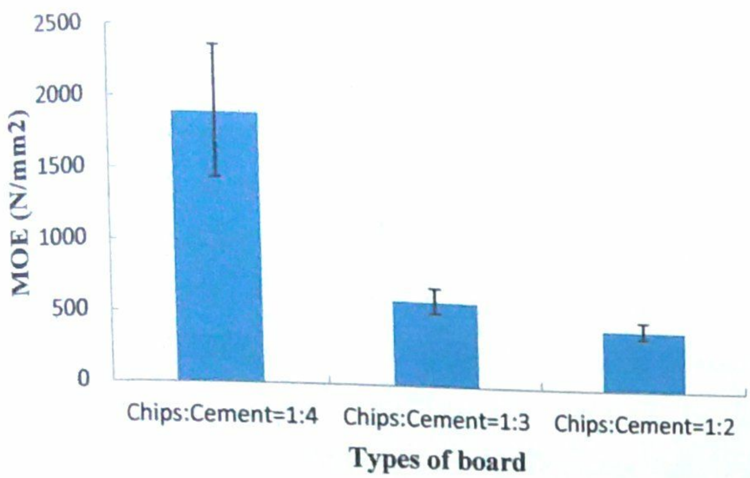

Fig.4.7: Modulus of Elasticity of cement-bamboo composites from Muli Bamboo (*Melocanna baccifera*) chips.

From the analysis of variance (Appendix-7), it has been found that, there is significant difference for Modulus of Elasticity (MOE) among the ratio of bamboo chips and cement($DF=2, F=8.43$ and $P<0.0052$).

4.2 Discussion

The density of a board depends on the density of particles as well as amount of cement used. This study reveals that the average density of cement bonded particle board is 942.806 kg/m^3. In this observation, higher amount of cement show highest density and the reverse show lower density. In Nigeria, Erakhrumen *et al.*, (2008) found that the density of cement bonded particle board from only pine (*Pinus caribaea* M.) saw dust 1.79 gm/cm^3. He also found that cement: sawdust-coir ratio of 2:1 was 1.54 gm/cm^3 and cement: sawdust-coir ratio of 2:2 was 1.13 gm/cm^3 lower than sawdust. In Bangladesh, Study on *Albizia falcataria* wood for cement bonded particleboard (Biswas *et al.*, 1997) shows that the board density was about 976 Kg/m^3. The average density in bison factory (Anon, 1975) found that the cement bonded particle board from saw dust was 1250 Kg/m^3. The target density of cement bonded particle board is 1.2 gm/cm^3 (Anon, 2001).

From this study, It has been found that the moisture content of cement bonded particle board was ranges from (9-18) %. In bison factory (Anon, 1975) in china found that the cement bonded particle board from saw dust, Moisture content ranges from 3% to 9% at Factory Point.

In this study water absorption of cement bonded particle board ranges from (4.091-29.003) %. Water absorption (WA) is lower in chip: cement ratio of 1:4. In bison factory (Anon, 1975) in china found that the cement bonded particle board from saw dust, water absorption of the board is 27%. The water absorption of the various board specifications was higher where there was reduced proportion of cement inclusion. This pattern of water absorption variations is in conformity with the observation of many researchers (Badejo, 1987; Oyagade, 1995; Ajayi, 2004; Del Meneéis *et al.*, 2007). Lowering the cement proportion in composite manufacture might lead to large quantity of exposed particles and free internal spaces which are almost always associated with low density boards, a possible contributory factor to this water absorption pattern and likely instability of board. Compared to low density particleboards, high density particleboards have lower porosity so that particles and cement can interact with each other more easily to form stronger crosslink (Zheng et.el., 2007).

Study on *Albizia falcataria* wood for cement bonded particleboard in BFRI (Biswas *et al.*, 1997) shows that water absorption of the board was 27.8% after 24 hrs submersing into water. Erakhrumen *et al.*, (2008) observed 23.4%, 30.6% and 54.0% water absorption for only pine (*Pinus caribaea* M.) sawdust, sawdust: coir ratio (2:1) and sawdust: coir ratio (2:2) for cement bonded particle board. This result is at variance with some studies that have identified coconut husk as a material with high lignin content with low affinity for moisture which thus, act as a barrier for cellulose microfibril, for moisture absorption but consistent with outcome of studies such as Rahman and Khan (2007) which identified coconut husks fibres as being hydrophilic due to the presence of hydroxyl groups from cellulose and lignin components. Aggarwal (1992) found that water absorption of coconut coir cement bonded board is 14-16%.

Thickness swelling in this study ranges 8.40% to 15.368% and linear expansion 3.169% to 8.486%. Given 24 hours soaking a particle (bonded with same Portland cement) was found to swell only 2.1% and with no tendency to delaminate after 24 hrs. This implies that cement bonded particleboard made from Muli bamboo chips would be a resistant and dimensionally stable product against humidity. Study on *Albizia falcataria* wood for cement bonded particleboard (Biswas *et al.*, 1997) shows that Thickness swelling of the board was 2.87% after 24 hrs submersing into water. Erakhrumen *et al.*, (2008) observed 12.3%, 4.6% and 2.9% thickness swelling for only pine (*Pinus caribaea* M.) sawdust, sawdust: coir ratio (2:1) and sawdust: coir ratio (2:2) for cement bonded particle board. Aggarwal (1992) found that thickness swelling of coconut coir cement bonded board is less than 1.2%. In bison factory (Anon, 1975) China found that the thickness swelling of cement bonded particle board was 1.0%.

In this study, the average Modulus of Rupture (MOR) of cement bonded wood ranges from 1.2 Nmm^2 to 4.80 Nmm^2 and MOE of cement bonded wood ranges from 437.132 Nmm^2 to 1889.45 Nmm^2. The bamboo chips: cement 1:4 shows the highest modulus of rupture (MOR) and the bamboo chips: cement 1:2 shows the lowest modulus of rupture (MOR). The bamboo chips:

cement 1:4 the highest Modulus of Elasticity (MOE) and the bamboo chips: cement 1:2shows the lowest Modulus of Elasticity (MOE). Study on *Albizia falcataria* wood for cement bonded particleboard (Biswas *et al.*, 1997) shows that the average bending strength value was observed to be 59 Kg/cm^2 with the maximum being 66 Kg/cm^2 and the minimum 51 Kg/cm^2. Erakhrumen *et al.*, (2008) observed 46.9 Nmm^2, 51.0 $Nmm^2$and 28.1Nmm^2 MOR for only pine (*Pinus caribaea* M.) sawdust, sawdust: coir ratio (2:1) and sawdust: coir ratio (2:2) for cement bonded particle board. Aggarwal, (1992) found that MOR of coconut coir cement bonded board is 9-11 MPa. In bison factory (Anon, 1975) China found that the MOR of cement bonded particle board was 9 N/mm^2.

For MOE, Erakhrumen *et al.*, (2008) observed 7813 Nmm^2, 11185 Nmm^2 and 4171 Nmm^2 MOE for only pine (*Pinus caribaea* M.) sawdust, sawdust: coir ratio (2:1) and sawdust: coir ratio (2:2) for cement bonded particle board. Aggarwal (1992) found that MOE of coconut coir cement bonded board is 2500-2400 MPa. In bison factory (Anon, 1975) China found that the MOE of cement bonded particle board was 3000 Nmm^2.

The strength properties were also influenced by board density, with higher density boards possessing higher strength properties (MOR and MOE). These findings are in agreement with studies by Ajayi (2002) and Zheng *et al.*, (2007). It was also reported by Wang and Sun (2002) and Papadopoulos *et al.*, (2002, 2004) that the density of particleboards made from wheat straw, coconut chips, and bamboo chips significantly affected the particleboard properties. The increase in water resistant properties as density increased was also in conformity with results from the experiment by Zheng *et al.*, (2007).

Panel fabricated at higher density generally exhibits higher bending strength. (Kuroki *et al.*, 1993) pointed out that low board density (1000 Kg/m^3 or below) would not result in property levels that are highly desired. He also stated that in order to achieve a bending strength of 120 130 Kg/m^2 the density has to be increased to 1150 Kg/m^3. In a case study prepared for the FAO

(Anon, 1975), it is reported that the bending strength of the board at density level 1000Kg/m^3 and a wood cement ratio of about 1:18 is approximately 25% lower than the recommended standard value. It may therefore, be inferred that the bending strength as observed in this study could be improved by increasing the density of the panel and by using longer and thinner flacks.

The reduction in the values of MOR and MOE obtained as a result of reduction in the cement component in the mixing ratios is in conformity with similar studies on cement-reinforced lingo-cellulosic composites. The result also showed that boards with higher cement content had higher density values (Eusebio *et al.*, 1998; Latorraca and Iwakiri, 2000; Zhou and Kamdem, 2002). Irrespective of this, ways by which stable low-density cement-bonded composites, with reduced cement to particle ratio, can be made should be of priority as high density boards are difficult to handle, cut, nail and transport (Zhou and Kamdem, 2002) coupled with the cost implication associated with higher content of cement component for its production. It has also been noted that higher cement contents do not always result in continuous further property increase in composite boards (Del Meneéis *et al.*, 2007).

CHAPTER FIVE
CONCLUSION

CHAPTER FIVE

CONCLUSION

Cement bonded particle board from Muli Bamboo chips is a cheap constructional material and it can be manufactured from conventional process. Bamboo-cement composite materials are becoming increasingly accepted for use in the construction industry because they combine some of the advantages of both constituents. Bamboo can serve as a low-cost material to help improve the toughness, strength-to-weight ratios, and creep deflection properties of cement when these two materials are combined to form a composite material. Bamboo-cement composites in the form of cement-bonded particleboard has been used in applications such as roof and highway sound barriers, They are used in building construction because they offer properties of excellent sound absorption, fire resistance, thermal motion and dimensional stability, as well as sound structural performance. They have superior decay and insect resistance capacity. From this study, we can observe that:

- Bamboo is a very cheap material and if we use this for manufacturing cement bonded particle board, this material will be valuable.
- Increasing cement content decreases moisture content, water absorption thickness swelling and linear expansion of composites.
- It has less swelling and linear expansion capacity which is very much essential for special construction purposes. It may solve the dwelling problem of poor people.
- It was also found that increasing cement content increases density, MOE and MOR.
- Though bamboo-cement (1:4) composites showed better physical and mechanical properties compared to the commercial particleboards in Bangladesh, but further research is recommended to reduce the cement content in composite manufacturing.

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APPENDIX -1

APPENDIX-1.2

Moisture content

Analysis of Variance Procedure

Dependent Variable: MC

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	336.69039837	17.45	0.0001
Error	15	144.67270895		
Corrected Total	17	481.36310732		

R-Square	C.V.	MC Mean
0.699452	24.23156	12.8164088

Source	DF	Anova SS	F Value	Pr > F
TRTMENT	2	336.69039837	17.45	0.0001

Analysis of Variance Procedure

T tests (LSD) for variable: MC

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 15 MSE= 9.644847
Critical Value of T= 2.13
Least Significant Difference= 3.8217

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRTMENT
A	18.905	6	T3
B	10.275	6	T2
B	9.269	6	T1

APPENDIX-1.3

Water absorption

Analysis of Variance Procedure

Dependent Variable: WA

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	1800.19971504	113.02	0.0001
Error	15	119.46104829		
Corrected Total	17	1919.66076333		

R-Square	C.V.	WA Mean
0.937770	17.17087	16.4352129

Source	DF	Anova SS	F Value	Pr > F
TRTMENT	2	1800.19971504	113.02	0.0001

Analysis of Variance Procedure

T tests (LSD) for variable: WA

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 15 MSE= 7.96407
Critical Value of T= 2.13
Least Significant Difference= 3.4728

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRTMENT
A	29.300	6	T3
B	15.090	6	T2
C	4.915	6	T1

APPENDIX-1.4

Thickness swelling

Analysis of Variance Procedure

Dependent Variable: TS

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	73.67645927	5.13	0.0502
Error	6	43.05643463		
Corrected Total	8	116.73289390		

R-Square	C.V.	TS Mean
0.631154	22.98943	11.6523971

Source	DF	Anova SS	F Value	Pr > F
TRTMENT	2	73.67645927	5.13	0.0502

Analysis of Variance Procedure

T tests (LSD) for variable: TS

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 6 MSE= 7.176072
Critical Value of T= 2.45
Least Significant Difference= 5.352

Means with the same letter are not significantly different.

T Grouping		Mean	N	TRTMENT
	A	15.368	3	T3
B	A	11.181	3	T2
B		8.408	3	T1

APPENDIX-1.5

Linear expansion

Analysis of Variance Procedure

Dependent Variable: LE

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	42.47017845	11.75	0.0084
Error	6	10.84214546		
Corrected Total	8	53.31232391		

R-Square	C.V.	LE Mean
0.796630	23.28779	5.77236471

Source	DF	Anova SS	F Value	Pr > F
TRTMENT	2	42.47017845	11.75	0.0084

Analysis of Variance Procedure

T tests (LSD) for variable: LE

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 6 MSE= 1.807024
Critical Value of T= 2.45
Least Significant Difference= 2.6857

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRTMENT
A	8.487	3	T3
B	5.661	3	T2
B	3.169	3	T1

APPENDIX-1.6

MOE

Analysis of Variance Procedure

Dependent Variable: MOE

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	6311248.83342	8.43	0.0052
Error	12	4492072.17437		
Corrected Total	14	10803321.00779		

R-Square	C.V.	MOE Mean
0.584195	62.60642	977.268446

Source	DF	Anova SS	F Value	Pr > F
TRTMENT	2	6311248.83342	8.43	0.0052

Analysis of Variance Procedure

T tests (LSD) for variable: MOE

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 12 MSE= 374339.3
Critical Value of T= 2.18
Least Significant Difference= 843.11

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRTMENT
A	1889.5	5	T1
B	605.2	5	T2
B	437.1	5	T3

APPENDIX-1.7

MOR

Analysis of Variance Procedure

Dependent Variable: MOR

Source	DF	Sum of Squares	F Value	Pr > F
Model	2	34.55640593	16.27	0.0004
Error	12	12.74293308		
Corrected Total	14	47.29933901		

R-Square	C.V.	MOR Mean
0.730590	37.90428	2.71866593

Source	DF	Anova SS	F Value	Pr > F
TRTMENT	2	34.55640593	16.27	0.0004

Analysis of Variance Procedure

T tests (LSD) for variable: MOR

NOTE: This test controls the type I comparisonwise error rate not the experimentwise error rate.

Alpha= 0.05 df= 12 MSE= 1.061911
Critical Value of T= 2.18
Least Significant Difference= 1.42

Means with the same letter are not significantly different.

T Grouping	Mean	N	TRTMENT
A	4.8057	5	T1
B	2.1099	5	T2
B	1.2405	5	T3